Delta Water Quality

CALFED Bay-Delta Program

August 2007

This paper presents summaries of the most important water quality issues addressed by the CALFED Bay-Delta Program. These issues are also essential to the Delta Vision goal of managing the Delta as a sustainable ecosystem that continues to support critical environmental and economic functions. It is intended to provide a brief overview of the status and future of some of the Delta's highest priority water quality problems. The body of the report is in the form of a series of fact sheets covering individual water quality topics. The key themes and conclusions from individual fact sheets are synthesized herein.

The water quality topics covered are: Dissolved Oxygen, Pesticides, Selenium, Mercury, Toxicity of Unknown Origin, and Drinking Water Quality. Although not a comprehensive list of Delta water quality issues, these are the issues that were and are considered some of the highest priorities for the CALFED program. Salinity, as an ecosystem water quality issue is not included here because it is dealt with at length elsewhere in the Delta Vision briefing materials. Nutrients as they relate to the aquatic food web are also not covered here because they have not been clearly defined as impairing beneficial uses of Delta water.

This report was prepared based on a series of interviews with subject matter experts, available reports, and information available on the internet. It was funded in large part by the CALFED Science Program through a contract with Brown and Caldwell Consulting, Inc. The fact sheets were finalized and reviewed by CALFED Water Quality Program and Science Program staff and CALFED implementing agency staff. The project was managed by the CALFED Water Quality Program. Each fact sheet includes biographical information about the experts interviewed, references, and web sites for further information.

Key Themes

Several cross-cutting themes emerged during the preparation of this report.

Persistent non-point source problems

The water quality problems addressed by CALFED program are large scale, persistent, and difficult problems that tend to cross jurisdictional lines and are not amenable to single agency regulatory solutions. They are typically non-point source pollution problems resulting from current or historical land use activities, with multiple contributing factors, which are resistant to simple control or removal processes. For example, selenium in agricultural drainage and runoff from the west side of the San Joaquin Valley is transported downstream entering the food chain through algae as it moves through the system. In Suisun Bay it is taken up by clams which are in turn eaten by sturgeon. Concentrations of selenium in sturgeon tissues are high enough to affect the health of this long lived and economically important fish species. Low dissolved oxygen concentrations in the Stockton Deep Water Ship Channel is another difficult and complex water quality problem. It is linked to nutrients from agricultural runoff, dredging of the ship channel, operation of the State and Federal water projects, and municipal wastewater discharges. The Regional Water Quality Control Board can't correct the dissolved oxygen problem by simply limiting wastewater discharges, their primary tool for pollution control. All of the major Delta water quality issues are similarly geographically and institutionally complex.

Potentially conflicting goals

There are several actual and potential conflicts between the various uses of Delta water and land from a water quality perspective. The Delta is serving as an agricultural water supply, a municipal water supply, and a habitat for aquatic and terrestrial species. The Delta also, out of economic and geographic necessity, serves to transport and break down wastes from farms and cities. The habitat and water quality desired to support the aquatic food web may make municipal water use difficult or even impossible. Similar conflicts may exist between agricultural water quality goals and ecosystem restoration goals. For example, increasing the organic carbon supply at the base of the aquatic food web is an important ecosystem need. However, municipal water users want the lowest possible organic carbon concentration because of its role in disinfection byproduct formation. Another example of potential conflict is between two ecosystem goals: restoration of wetland habitat and reducing mercury impacts on wildlife. Recent studies suggest that creation of seasonally flooded habitat could greatly increase the amount of mercury entering the aquatic food web and could have an adverse impact on birds, mammals, and people eating Delta fish.

Delta flows

The flow of water (hydrodynamics) within and through the Delta varies greatly both in space and time. The quality of water at any point in the Delta is largely dependent on this flow. Changes due to rainfall, water operations (diversions, conveyance, and storage), or tides can have dramatic effects on water quality. The effect of flow on water quality is clearly seen in Stockton Ship Channel dissolved oxygen concentrations. Low dissolved oxygen concentrations are almost never observed when net flow through the channel is above 2000 cubic feet per second.

Another example is the variation in water quality in south Delta SWP and CVP diversions. This water quality is highly dependent on pumping rate, the amounts of Sacramento and San Joaquin River water entering the Delta, and the re-routing of Delta flows by gate and barrier operations. Under most flow conditions, nearly the entire flow of the San Joaquin River gets drawn to the south Delta pumps and diverted.

One of the most prominent flow related features of Delta water quality is the "freshwater corridor" extending from the point where the Sacramento River enters the Delta to the south Delta pumps. This swath of high quality water moving across the central Delta may be one reason that this area is relatively free of significant water quality problems. High quality water moving through the central Delta dilutes many tributary and in-Delta sources of pollutants.

The ability to analyze the mixing and flow of water in and around the Delta through the use of computer models is a powerful water quality management tool. Advanced hydrodynamic and water quality models have greatly increased our understanding of the Delta. For example, recent studies of water flow in and around Franks Tract revealed the important influence of flow in two west Delta channels on salinity at the south Delta pumps.

Monitoring, assessment, and research

Nearly ever person interviewed said that a continued or increased level of monitoring, assessment, and research was needed to effectively address Delta water quality issues. Progress in improving water quality is often limited by a lack of dedicated funding and resources for monitoring, assessment, and research in the Delta and its tributaries. One of the most important contributions of the CALFED program has been the great increase in knowledge about the Delta environment. A prime example is the development of a powerful technique for directly measuring mercury exposure in the aquatic food chain developed by University of California researchers. By measuring methylmercury in small fish over a broad geographic area, this research has greatly increased our knowledge about which areas are the most important mercury sources and the physical conditions that increase methylmercury production. This research will help restoration project planners to design floodplain restoration and place wetlands in ways that minimize mercury impacts.

Conclusions

Protecting and improving water quality is a struggle that will continue regardless of changes to Delta conveyance and land use. However, decisions that change the quality and quantity of water entering the Delta or the movement of water through the Delta will have a profound effect. If the major water projects ultimately route water around the Delta, the remaining Delta water sources will have a proportionately increased influence on Delta water quality. For example, a significant fraction of the selenium load now transported by the San Joaquin River is now exported from the basin by the CVP and SWP projects. If water is no longer diverted from the south Delta, this selenium load will remain in the system adding to the selenium contamination problem in Suisun and San Francisco Bays. More precise predictions of water quality changes will require rigorous and detailed analysis of the projected flow changes in the system, land use changes, and realistic assessments of available mitigation methods. Predictions of conditions due to future risk factors may require more sophisticated modeling than currently exist.

Some bright spots

- There is the potential for significant reduction in mercury loads through a few key actions such as removing contaminated sediment from the Cache Creek Settling Basin and cleaning up some high priority mercury mines.

- Not all wetlands are bad for mercury. Knowledge and proper design may avoid significant impacts (Mercury monitoring in biosentinel fish species is an essential tool).
- Technologies exist for capturing and sequestering some of the San Joaquin Valley salt and selenium load.
- Conveyance alternatives that will reduce salt and other pollutant loads in the water supply for the San Joaquin Valley and will also help to improve San Joaquin River water quality.
- Conveyance alternatives could also greatly reduce bromide concentrations in municipal supplies.
- Changes to through Delta conveyance, such as installation of an operable barrier in a single west Delta channel (Franks Tract Project) or changing the way the Delta Cross Channel is operated, could reduce salinity and bromide at the south Delta pumps.
- Increasing flow in the Stockton Ship Channel, aeration, and reduced ammonia discharges could greatly improve dissolved oxygen conditions.
- Pesticide-associated toxicity in the Delta has decreased since the early 1990s. This suggests that pesticide regulatory programs and cooperative efforts are having an effect.
- Drinking water treatment technology advances and investments have been able to keep pace with tighter regulations.

Continuing and emerging causes for concern

- The pelagic organism decline (POD) continues and a better understanding of water quality linkages is needed.
- Pesticides and toxicity are still regularly observed and long term effects of low level pesticide exposures are not fully understood.
- We can reduce but not completely eliminate pesticides contamination from agriculture.
- Bromide is high in the Delta and is associated with the more toxic disinfection byproducts in tap water.
- Climate change could change flow patterns and increase water temperatures adding to a broad range of water quality problems.
- The trend towards increased urbanization of the Central Valley and Delta continues and pollutants continue to be a problem in urban runoff.
- Increased demand for water within the Delta watershed will tend to reduce in stream flow and exacerbate water quality problems.
- Changing Delta conveyance may reduce or eliminate the "incidental benefit" of current through-Delta conveyance. That is, high quality water moving through the central Delta dilutes many tributary and in-Delta sources of pollutants.
- Coordinated performance measure development is significantly hindered by a lack of dedicated resources.

Recommendations

- Continue to support the dissolved oxygen and mercury programs, cooperative pesticide control efforts, the Interagency Ecological Program, and other monitoring and assessment programs
- Support performance measure development.
- Implement high priority mercury source remediation projects.
- Increase efforts to address urban and agricultural water quality impacts.
- Support efforts to develop selenium fish tissue standards and continue to implement control programs to achieve those standards.
- Create a governance environment that enhances interagency coordination and cooperation. This is essential to continued progress on these more difficult water quality challenges.
- Make resources available to bring accurate water quality information into the Delta planning process and to adequately monitor the system as changes take place.
- Continue to support grant programs for water quality research, remediation, source control, treatment technology, and pilot projects.

Finally, there are several upcoming reports that will address environmental water quality, ecosystem restoration, and drinking water quality in much greater detail. The CALFED Science Program is preparing a State of Science for the Bay-Delta System Report. The Ecosystem Restoration Program, working with the Science Program and subject matter experts, is preparing a series of ecosystem and species conceptual models as part of a Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). The CALFED Ecosystem Restoration Program is preparing a final Stage 1 assessment of progress towards its ecosystem restoration goals and the CALFED Water Quality Program is preparing a final of Stage 1 assessment of progress towards drinking water quality goals.

Dissolved Oxygen

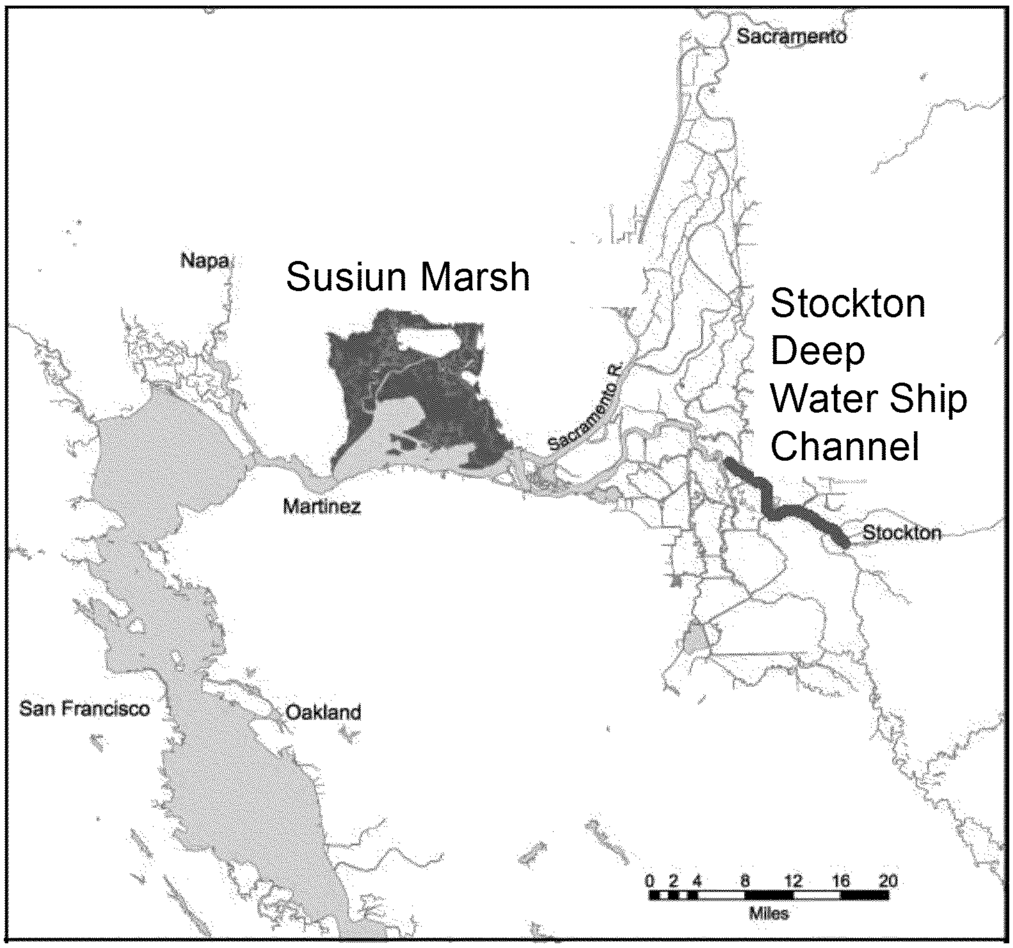
CALFED BAY-DELTA PROGRAM

Problem

Dissolved Oxygen (DO) is the form of oxygen upon which most aquatic life depends. A minimum of 5 mg/L of DO is generally considered necessary to avoid impacts on fish and other aquatic species. Low DO concentrations can lead to fish kills and degraded habitat, and in parts of the Delta may act as a barrier to migrating salmon. Low DO can also aggravate other effects, such as release of metals from bottom sediments and conversion of mercury to methylmercurcy.

Sources and Causes

DO is consumed by microbial processes such as respiration and nitrification. Factors that increase the risk of DO sags include nutrient (organic carbon, nitrogen and phosphorous) loading, high water temperatures, water depth, algal blooms, and long residence times due to decreased flows or other physical conditions.



Base figure from http://www.iep.ca.gov/suisun/map/index.html

Geographic Extent

Two key areas (shown in red in the figure above) within the CALFED solution area have been identified as needing DO management: the Stockton Deep Water Ship Channel and Suisun Marsh. The Stockton Deep Water Ship Channel, is a dredged segment of the San Joaquin River within the Delta. Within this channel reach, DO periodically drops below 5 mg/L, and sometimes dips below 2 mg/L. This creates a "dead spot" of degraded habitat that acts as a barrier to fish passage to the San Joaquin River. Suisun Marsh is surrounded by managed wetlands that contribute high organic matter and nutrient loadings. This is especially a problem during the late summer and early fall. Old and Middle Rivers in the South Delta are also impaired due to low DO conditions and were added to the State Water Board 303(d) list in 2002. The nature and causes of these two impairments in the South Delta are not well understood.

Conceptual Model

The Central Valley Regional Water Quality Control Board (CVRWQCB) attributes DO depletion in the Stockton Deep Water Ship Channel to three key factors; inputs of oxygen demanding substances, increased channel depth due to dredging, and reduced net flow. The relative contribution of these factors and some of the details still need to be worked out. One contributing mechanism is the physical configuration of the channel. The depth of the channel, combined with the low flow in the San Joaquin River, cause settling

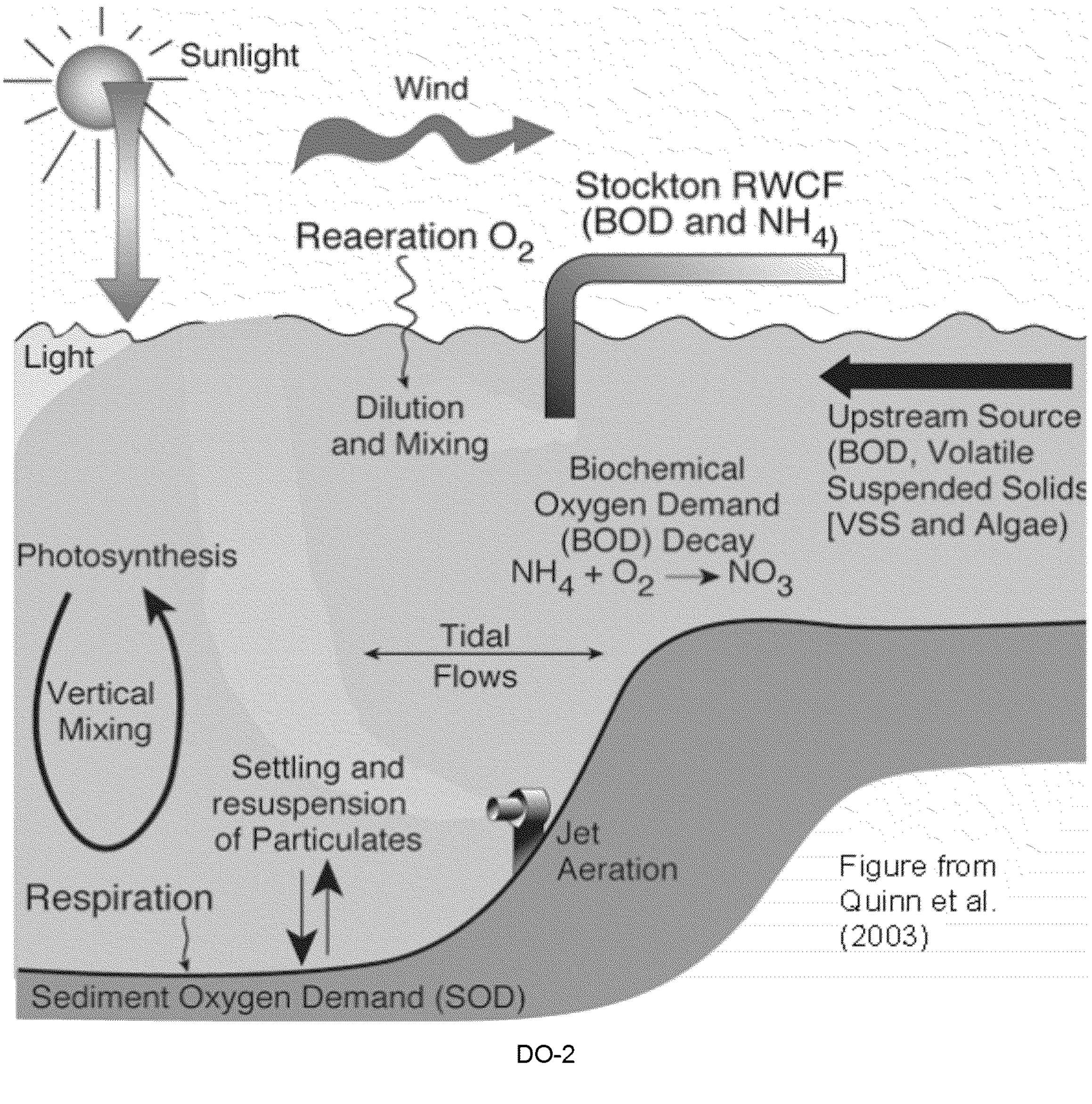


Figure from Quinn et al. (2003)

and reduced light conditions for the algae flowing into the channel from the upstream San Joaquin River watershed. A significant portion of this algae dies and exerts an oxygen demand in the water column.

Another contribution is ammonia entering the system from the City of Stockton wastewater treatment plant. Ammonia is nitrified in the channel, creating biochemical oxygen demand (BOD), adding to the oxygen demand from dying algae from the San Joaquin River.

Another DO depletion mechanism currently under study is that a feedback loop is created when small zooplankton are killed by low DO. Their decaying bodies release additional ammonia, which is nitrified, further depleting DO. The figure above illustrates the major contributing mechanisms.

In Suisun Marsh, the seasonal trends suggest that decaying organic matter is a factor that increases available organic carbon, which then consumes oxygen through microbial respiration. Drainage of water from wetlands managed for waterfowl, rich in nutrients and organic matter, creates high levels of chemical and biochemical oxygen demand in adjacent sloughs that add to the seasonal DO depletion driven by plant decay.

Corrective Actions

The Central Valley Regional Water Quality Control Board (CVRWQCB) has developed a DO Total Maximum Daily Load (TMDL) for the Stockton Deep Water Ship Channel. A TMDL is a regulatory mechanism for addressing water quality impairments by establishing load limitations on the various contributing sources. The CVRWQCB adopted a phased TMDL in 2005 that requires study of the sources of oxygen demanding substances into the channel, and recommends certain actions be taken to address the effect of channel geometry and low flow on the impairment. Based on the results of the studies and any actions taken, the CVRWQCB will develop a final TMDL in 2009 to establish more detailed limitations.

This phased TMDL will also allow time for implementation of stakeholder-developed load reduction strategies, and testing of aeration systems to alleviate low DO events through direct injection of oxygen into channel waters.

A major 3-year study has been undertaken to understand the sources of algae and the factors controlling their growth in the San Joaquin River. Factors contributing to or controlling this algae growth include algae inputs from tributaries and agricultural drainage, nutrients, light conditions, residence time, and zooplankton grazing. This study is also generating a model to predict the algae concentrations within the San Joaquin River based on these and other factors. Studies of how these loads are converted to oxygen demand in the channel are also required, but no progress has been made in locating the needed sponsor or funding

Next Steps

The CVRWQCB has been charged with the development of the DO TMDL, but it lacks the ability to directly influence flow and channel geometry or require the mitigation of their effects. As recommended in the phased DO TMDL, responsibility for actions to mitigate these non-load related factors rests with the responsible agencies (i.e. US Army Corps of Engineers for the channel, and DWR, and the US Bureau of Reclamation, and others for flow). These agencies need to take the lead in evaluating and implementing the actions needed.

To address the loads of oxygen demanding substances contributing to the DO impairment, studies need to be completed that identify the sources of these substances and their linkage to the impairment in the channel. Much of the funding for these studies has come from CALFED and the continued support of the program is needed until they are complete. Once complete the CVRWQCB can finalize the TMDL and the stakeholders can begin to develop management strategies addressing algae and other oxygen demanding substances. Studies of the effectiveness of direct mechanical aeration are on-going (depicted by the jet aerator preceding Figure). A large pilot system located on the Stockton Deep Water Ship Channel at Rough and Ready Island is nearly ready for startup.

Once the above studies are completed and a better overall understanding of the system is obtained, coordinated management options can be considered . Basic considerations for developing a long-term solution include:

- What water management actions (or associated mitigation measures) can be taken in the Delta to improve DO in the channel, while balancing other ecosystem needs or beneficial uses in the Delta
- What are appropriate algae levels for the San Joaquin River, and how best to reasonably and effectively control them.
- How to mitigate the effect of the channel, while allowing for ship traffic and continued use of the Port of Stockton.

To address those questions and propose solutions, closer coordination between the CVRWQCB, the DWR, the USBR, the USACOE and other stakeholders involved in the San Joaquin River will be essential.

In Suisun Marsh, the availability of funding for research on treatment and Best Management Practices to reduce the impacts of drainage from managed wetlands has been a limiting factor. To address this, the State Water Resources Control Board approved a grant to evaluate a range of modified wetland management practices to reduce the discharge of water with high oxygen demand. This project is a collaboration between the Suisun Resource Conservation District, private landowners, US Geological Survey, DWR, DFG, UC Davis, and Wetlands and Water Resources, Inc.

For more information

This fact sheet was developed based on interviews with Dr. William Stringfellow of the Lawrence Berkeley Laboratory, Earth Sciences Division and Mark Gowdy, staff of the Central Valley Regional Water Quality Control Board.

Dr. Stringfellow has a Ph.D. in , Environmental Sciences and Engineering from the University of North Carolina at Chapel Hill; an M.S. in Microbiologyfrom Virginia Polytechnic Institute; and a B.S. in Environmental Health from the University of Georgia. His teaching and research experience includes the University of Pacific, the Lawrence Berkeley National Laboratory, and the University of California, Berkeley. His research and publications focus on microbiological processes important to eutrophication, DO management, and environmental remediation.

Mr. Gowdy holds a B.S. in Civil Engineering from the University of Illinois, and an M.S. in Environmental Engineering from the Illinois Institute of Technology. He is a Water Resources Control Engineer working in the San Joaquin River TMDL Unit, focusing on planning and policy to address dissolved oxygen and eutrophication problems in the watershed.

The dissolved oxygen interviews were supplemented with the following sources:

Quinn, W.T., Stringfellow, W.T., and Hanlon, J. (2003). Real-Time Management of Dissolved Oxygen in the San Joaquin River Deep-Water Ship Channel. Lawrence Berkeley Laboratory, Earth Sciences Division, Environmental Remediation Technology Program, Research Summaries 2002 – 2003. Available at: http://www-esd.lbl.gov/research_sums_02-03/environmental/quinn.html, last accessed on 6/25/2007

The San Joaquin River Dissolved Oxygen TMDL Technical Working Group's website: http://www.sjrdotmdl.org, last accessed on 7/2/2007

Suisun Marsh Program, 2006. Update on Suisun Marsh Plan, October, 2006. Available at: https://www.delta.dfg.ca.gov/suisunmarsh/charter/docs/Suisun_Marsh_Newsletter_Oct_2006.pdf, last accessed on 7/2/2007

Additional information on the Suisun Marsh Program is available at: http://www.iep.ca.gov/suisun/, last accessed on 7/2/2007

Mercury

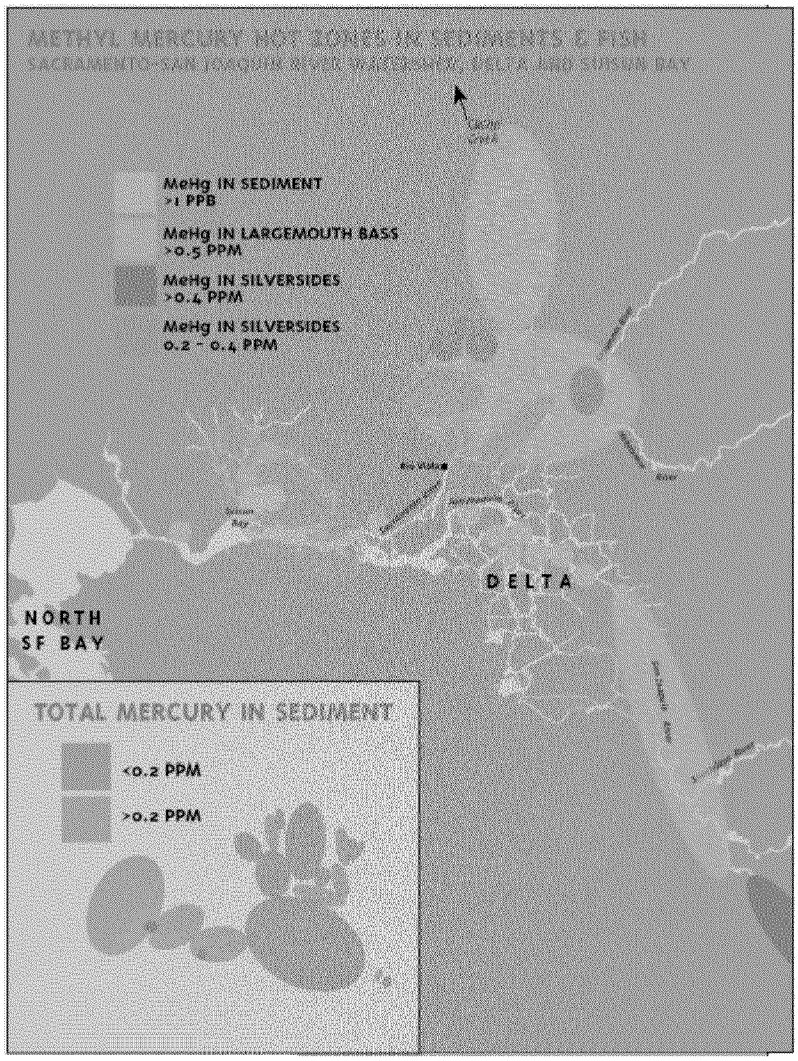
Problem

Mercury concentrations in some fish species in the Delta and San Francisco Bay are high enough to warrant fish advisories for human consumption. Studies of mercury in wildlife also indicate that there is cause for concern.

Mercury-enriched sediment contaminates extensive downstream reaches of streams and rivers, adjoining floodplains, and the Bay-Delta Estuary. Concentrations of methylmercury in some resident fishes exceed 0.3 mg/kg (parts per million) wet weight, the U.S. Environmental Protection Agency's fish-tissue criterion for protecting the health of humans who consume fish (Weiner et al, 2003). The Delta and many of its tributaries are on the State Water Board's 303 (d) list.of impaired water bodies because of mercury contamination.

Mercury in various, primarily inorganic, forms is transformed into methylmercury by bacteria in the environment. This methylmercury, initially present at very low concentrations, enters the aquatic food web and can accumulate to potentially dangerous levels in fish at the top of the food chain (such as Striped Bass and Largemouth Bass).

The State of California has issued health advisories for fish consumption due to mercury contamination for a number of water bodies in the Delta and its watersheds. Exposure to methylmercury is of greatest risk to children and developing fetuses therefore health advisories are more stringent for children and women of child bearing age. Although mercury concentrations in fish vary geographically in the Bay-Delta system, there are levels of concern in all areas. The mercury problem in the Delta started with the Gold Rush and has continued to the present. It will take a substantial and sustained effort to significantly reduce mercury concentrations in Delta fish.



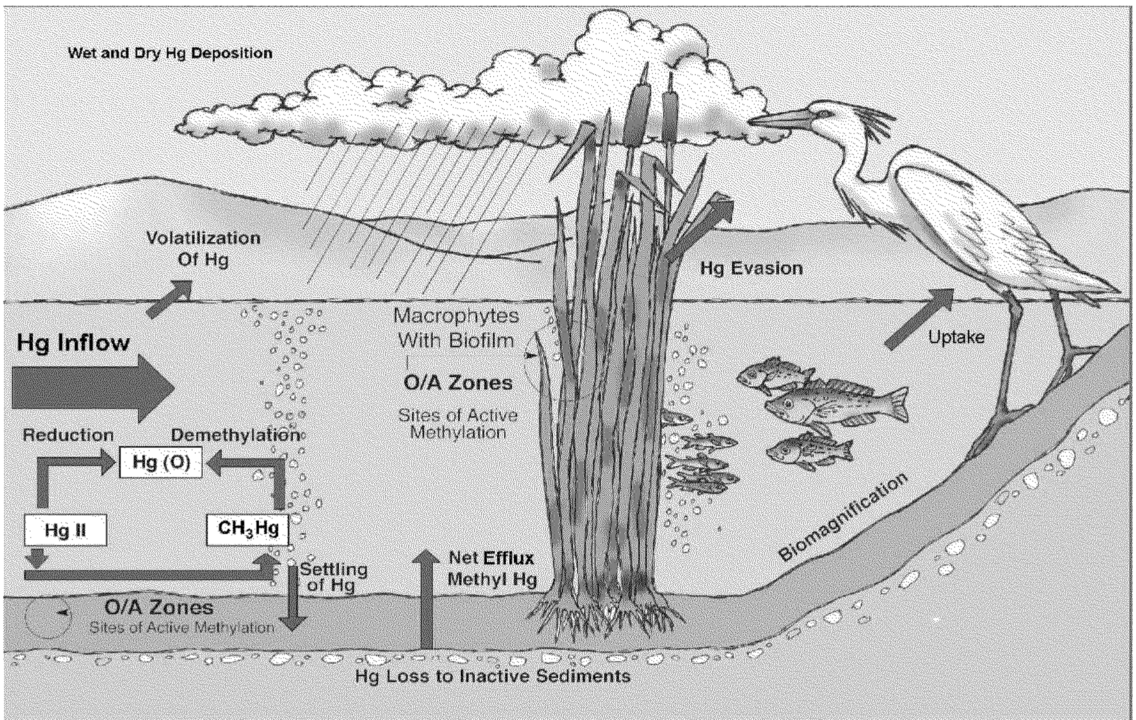
Although mercury is found at levels of concern throughout the Bay-Delta system, monitoring of sport fish (Largemouth Bass) and prey species (Silversides) indicate that methylmercury production is highest in Delta tributaries. (CALFED Science Program 2005)

Sources and Causes

Much of the mercury present in Bay-Delta watersheds is the legacy of nineteenth century mining activity. Mercury extracted from mines in the Coast Ranges was used to recover gold in the placer mining operations of the Sierra Nevada. There are numerous former mercury mine sites that currently discharge mercury into Delta tributaries, and the tributaries themselves have mercury contaminated sediments. Former gold mining sites also discharge mercury; many of these are located upstream of popular fishing reservoirs. Atmospheric deposition, important in other regions because of emissions from coal fired power plants, has not gotten as much attention in California until recently, when emissions from oil refineries and other industrial sources were considered. Municipal wastewater discharges contribute a much smaller fraction of the mercury load, but receive a great deal of attention because their discharges are already regulated for other pollutants.

The pathway between inorganic mercury release into the environment and the toxic effects of mercury is complex and highly variable. The key step in this process is thought to be the conversion of inorganic mercury into methylmercury by bacteria. The significance of different sources depends in part on the relative ease that bacteria can take up mercury and convert it to methylmercury. Atmospheric sources are known to be more readily converted to methylmercury, which is why questions are being asked about releases from combustion sources. Concerns that municipal wastewater may be more readily methylated have led to applied studies to determine if this is the case.

Possibly more important than the availability of different mercury sources is the areas where transformations to methylmercury take place. The hotspots for this transformation process



Mercury (Hg) flowing into wetlands and other methylating areas, and depositing on those areas from the atmosphere, undergoes complex transformations. While the most common form is inorganic mercury (Hg II), transformation to methylmercury (CH3Hg) is the key to bioaccumulation in algae and subsequent biomagnification in the food web.
(Figure from Report by Tetra Tech on behalf of the Clean Estuary Partnership.)

are anoxic or oxygen poor sediments, because the bacteria that produce methylmercury thrive under these conditions. Wetlands have long been known as habitats where mercury is methylated but recent studies have shown that not all wetlands are the same. Some produce ten times more mercury than others. Some wetland areas even appear to consume methylmercury.

An unexpected finding that came out of the CALFED Mercury Project was the discovery that the Delta appears to be a net sink for methylmercury, rather than a source. The pattern of water flow through wetlands appears to be an important factor. Alternating wetting and drying of soils and sediments also seems to enhance methylmercury production. Understanding the specific physical and chemical factors that affect methylmercury production is a key step towards resolving the potential conflict between wetland restoration and mercury contamination.

Most mercury is transported through the system in or closely associated with sediment. Although all parts of the Central Valley have some mercury in the soils and sediment, some areas such as the Cache Creek sediment basin and the Yolo Bypass are known hot spots. Almost half of the methylmercury load to the Delta comes from the Yolo Bypass, which is less than 1% of the watershed area. This disproportionately high contribution makes reducing mercury inputs to the Bypass from mining-impacted tributaries such as Cache Creek a very high priority. Recent findings show that other river floodplains are also important methylmercury sources.

Methylmercury in the aqueous environment can be broken down by sunlight, microbial activity, bound to organic matter, or can be taken up by living organisms. Methylmercury enters the aquatic food web primarily through algae. Because methyl mercury binds strongly to proteins, it tends to be retained by living organisms and its concentration increases at each succeeding level of the food chain.

The CVRWQCB estimates that mercury concentrations in Largemouth Bass can be 6,500,000 times higher than the concentration in ambient water. Bass and other large predatory fish in the Delta and its tributaries often have tissue concentrations in the range of 0.5 to 1.0 mg/kg while the proposed fish tissue standard is 0.24 mg/kg. Fish lower on the food chain like sunfish and trout have much lower mercury concentrations.

Since exposure to mercury in fish depends on how much fish is consumed, the proposed standard assumes a certain amount of fish consumption. People who eat more fish are at more risk for mercury toxicity. Mercury advisories for fish provide recommended limits on the amount of particular fish species people should consume. Since children and women who are or may become pregnant are at greater risk, their recommended limits on fish consumption are lower.

Because correcting the mercury problem will take a long time, an important action area is communicating to people who fish the Delta for food about safe eating habits – i.e. what species are considered safe, and what appropriate consumption levels are for adult males, women of child bearing age, and children. The CALFED Mercury Project conducted a study to find out more about the consumption habits of people who fish the Delta for food, and to determine the most effective communication strategy.

Birds and mammals that eat fish are also at risk from mercury contaminated fish. Fish make up most of the diet of terns, grebes, Bald Eagles, otters, mink, and many other birds and mammals. Calculations by the CVRWQCB based on the amount and type of fish consumed indicate that the fish tissue standard to protect wildlife should be nearly the same as the standard to protect humans. However, the science of mercury standards for wildlife protection is still developing and there are indications that mercury may be impacting reproduction of some wetland bird species. Unlike people, risk communication with wildlife is not an option, so it is important to continue working to reduce mercury to protect wildlife resources.

Corrective Actions

The CALFED Mercury Strategy, completed in 2004, organizes the state of knowledge and identifies important next steps in closing knowledge gaps and taking steps to reduce mercury loads and methylmercury production. While many of the important elements of the CALFED Mercury Strategy have been addressed, more effort on development and implementation of management practices is needed. In particular, it is important to move forward on cleaning up old mercury mines and restoring the downstream tributaries impacted by mining waste. Developing sound, science-based design and management guidance for wetland restoration projects is another key issue that needs funding to support implementation of the Delta Total Maximum Daily Load (TMDL) for Mercury and Methylmercury. While considerable progress has been made on risk assessment and communication, educating the public about fish consumption advisories will remain an ongoing need, and determining levels of consumption is essential to setting goals for target mercury concentrations in fish.

The Cache Creek TMDL and the Cache Creek Settling Basin. As mentioned above, Cache Creek has received focused attention because it is a mining impacted watershed upstream of the Yolo Bypass, a hot spot for mercury methylation. A Total Maximum Daily Load evaluation for Cache Creek has identified cleanup of the Abbott and Turkey Run Mines as a high priority in that watershed. Further downstream, the Cache Creek Settling Basin represents an opportunity to control loads on the watershed scale by improving the ability of the basin to trap sediments. For both upstream and downstream solutions, the key is identifying funding sources and working out legal issues of liability that could ward off potential funding partners.

Cleanup of other mine sites. Outside of the Cache Creek Settling Basin, there are numerous mercury and gold mining sites in need of cleanup and abatement. Some may still have existing responsible parties that require regulatory action to move forward. The New Idria Mercury Mine, which was at one time the second largest producer of mercury in North America, is an example of a mercury mine with identified potentially responsible parties. Discharges from that mine threaten the Mendota Pool and the San Joaquin River watershed. Many other mines may not have identifiable responsible parties, and so would require some mechanism for public funding. The application of mercury offset credits is one funding mechanism being considered by the State as a way of enabling municipal treatment plants to undertake mine site cleanups or other watershed projects in lieu of direct mercury reductions from the treatment plants that may be infeasible or provide little water quality benefit. Regardless of the funding mechanism, a key barrier to mine site cleanup by third parties without direct responsibility is the assurance of limited liability for "good Samaritans."

Adaptive Management Guidance for Wetland Projects. Restoration of wetland habitat is a high priority for CALFED's Ecosystem Restoration Program. The CALFED Mercury Project made considerable progress on some of the basic science questions about wetlands. This new information needs to be incorporated into specific guidance for the design, management, and monitoring of wetland restoration projects. Stakeholders with an interest in wetland restoration have also raised the issue of whether the responsibility for funding continued wetland BMP evaluation and improvement lies with the wetland owners and restorers, or if it is more appropriate to apply federal and State funds to address this natural resource issue.

Biosentinel, fish tissue, water and sediment monitoring. Because of the complexities of mercury transformation and bioaccumulation, "biosentinels" are important indicators of problem areas. The ideal biosentinel organisms are small, so that they respond to relatively short term changes (i.e., months), and don't move around a lot, so they reflect localized conditions. Clams and inland silversides are some biosentinels that have been used in the CALFED Mercury Project. Monitoring of larger fish provides information on the risk of exposure to human and wildlife consumers. Monitoring water and sediment helps identify mercury loads and areas where mercury is transformed to methylmercury. All of these monitoring tools need to be applied regularly and for a long period of time throughout the CALFED solutions area. During Stage 1, the information these monitoring tools provided enabled the development of a rational science-based strategy for managing mercury. Subsequent Stages should to continue to make monitoring funds available to ensure that mercury reduction programs initiated continue to make progress.

Study and model potential effects of changes to Delta hydrodynamics on organic carbon, sulfate, and mercury methylation. An important issue raised in the Delta Mercury TMDL is the role of organic carbon and sulfate on mercury methylation. Organic carbon feeds bacteria that methylate mercury, and those same bacteria depend on sulfate to respire carbon. Changes in the loading of organic carbon and the concentration of sulfate can cause dramatic increases or decreases in mercury methylation rates. This means that projects that cause major water diversions from the Delta, especially ones that increase the relative amount of water coming in from the San Joaquin River, will need to conduct proper environmental impact assessments on how proposed actions would affect mercury methylation and bioaccumulation.

Conduct Wildlife Assessments. Assessments funded by the CALFED Mercury Project have provided important information on endangered species that are currently at risk due to mercury exposure. These species include the Least Tern and the Clapper Rail, among others. Wildlife monitoring should continue in conjunction with ecosystem restoration projects to ensure that improved habitat is accompanied by species survivability.

Support efforts of the Department of Public Health (DPH) to educate the public about fish consumption guidelines. One of the most effective, immediate actions that can be taken to reduce risk to people is to ensure that they can access and understand consumption guidelines. Risk communication efforts like the CALFED partnership with DPH are an essential component of a mercury program. These efforts should target both subsistence and recreational fishing populations, and bridge any language gaps encountered. In addition to the DPH, County Public Health Departments can be useful agents of outreach to local communities.

Assess atmospheric emissions and deposition rates. Some mercury deposition monitoring has been undertaken in the San Francisco Bay Area, but more is needed on a statewide level. The San Francisco Bay Regional Water Quality Control Board recently required mercury air emissions monitoring information from Bay Area oil refineries. Other stationary sources around the State may need to be investigated.

Conduct pilot studies to evaluate the benefits of managing dissolved oxygen to reduce mercury in fish. Low oxygen is a known risk factor for mercury methylation. The Santa Clara Valley Water District has recently demonstrated through pilot studies that aeration of their reservoirs can reduce methylmercury. Pilot studies in the CALFED solution area should target areas with low dissolved oxygen, such as the Stockton Deep Water Ship Channel and some reservoirs, to evaluate whether this is a useful strategy to reduce mercury in fish.

For more information

This fact sheet was developed based on information presented at the CALFED Ecosystem Restoration Programs Second Annual Mercury Review Workshop in Sacramento, California, April 23 – 25, 2007. Follow up interviews were conducted with Patrick Morris and Chris Foe of the Central Valley Regional Water Quality Control Board, and Carol Atkins of the California Department of Fish and Game. Dr. Foe has a Ph.D. in Aquatic Ecology from UC-Davis, and has worked at the CVRWQCB for twenty years. Mr. Morris is a civil engineer with 14 years experience at the CVRWQCB in permitting, mines, and for the past five years, mercury TMDLs. Ms. Atkins has an M.S. in Soil Science and Plant Nutrition. She has worked at the State Department of Food and Agriculture, the State Water Resources Control Board, the CVRWQCB, CALFED and has done consulting for various local agencies through Harris and Company.

Interviews were supplemented with the following citable sources to develop this fact sheet:

Wiener, J. G., C. C. Gilmour, and D. P. Krabbenhoft (2003) Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration. Final Report to the California Bay Delta Authority. Sacramento, CA Available at: http://science.calwater.ca.gov/pdf/MercuryStrategyFinalReport.pdf, last accessed 8/14/2007.

Wood, M.L., Foe, C., and Cooke, J., 2006, Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury, Staff Report, Draft Report for Scientific Peer Review, Regional Water Quality Control Board – Central Valley Region. Available at: http://www.waterboards.ca.gov/centralvalley/programs/tmdl/deltahg.html, last accessed 8/09/2007.

Conceptual Model of Mercury in San Francisco Bay. Produced by Tetra Tech on behalf of the Clean Estuary Partnership, January 16, 2006. Available at http://www.cleanestuary.com/publications, last accessed 8/16/2007.

Mercury Technical Memorandum. Produced by Brown and Caldwell on Behalf of the South Bay Salt Ponds Restoration Project, August 4, 2004. Available at http://www.southbayrestoration.org/pdf_files/Final%20BC%20Mercury%20Technical%20Memo%20Aug%204%202004.pdf, last accessed on 8/16/2007.

Other web resources

The USGS has general information on methylmercury contamination at http://toxics.usgs.gov/definitions/methylmercury.html, last accessed on 8/9/2007, and information on mercury mines in the Bear and Yuba River watersheds at: http://ca.water.usgs.gov/mercury/bear-yuba/info.html, last accessed on 8/16/2007.

The San Francisco Estuary Institute posts frequent updates on mercury research and holds an annual mercury coordination meeting: http://www.sfei.org/rmp/mercury_newsletter/HgNews_home.html, last accessed 8/16/2007.

Reports produced by the CALFED Mercury Project are available at: http://loer.tamug.tamu.edu/calfed/, last accessed on 8/16/2007.

The San Francisco Bay Clean Estuary Partnership has produced several reports on mercury TMDL implementation, including a work plan for managing abandoned mines in the Bay Area. These reports are available at http://www.cleanestuary.com/publications/index.cfm#Mercury, last accessed 8/14/2007.

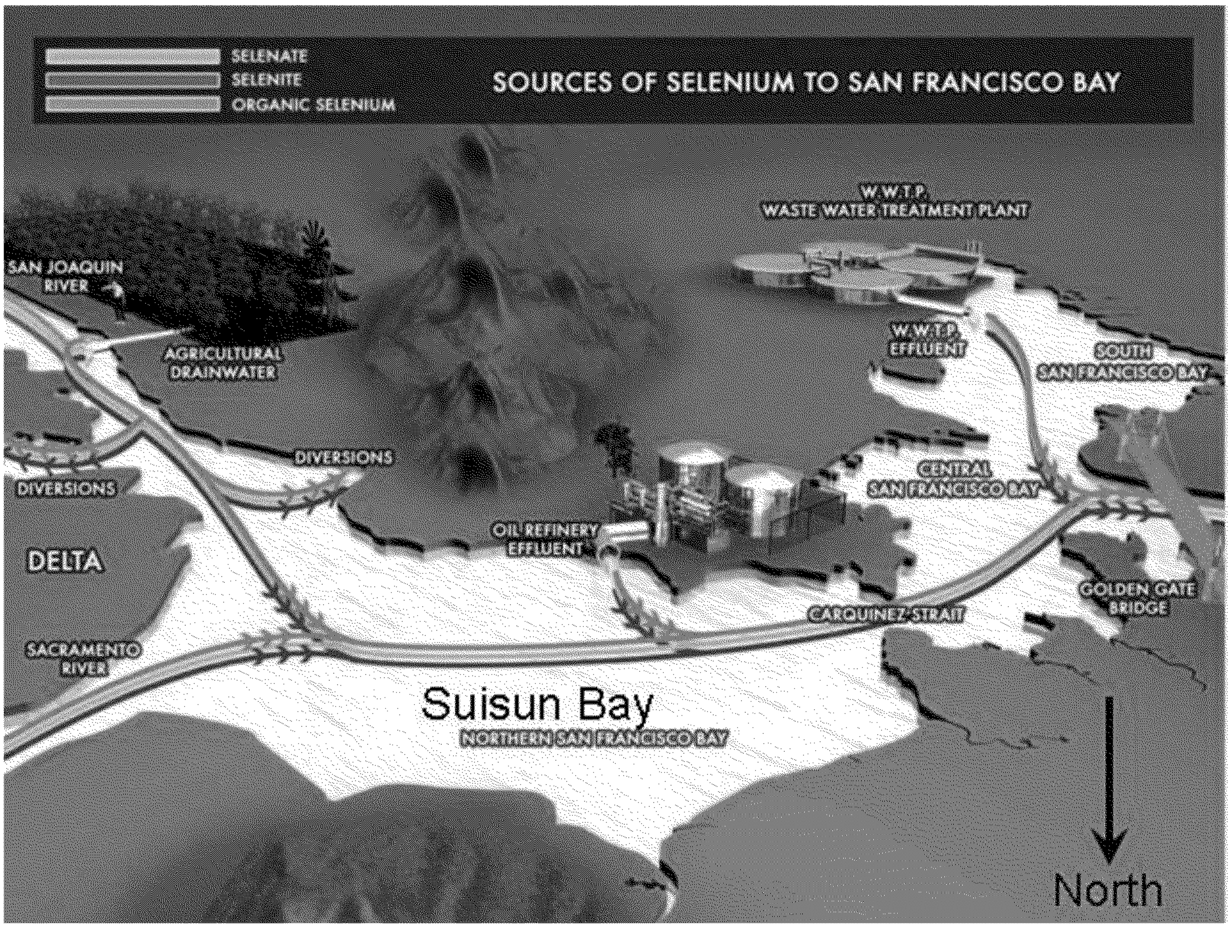
Information on the San Francisco Bay Regional Water Quality Control Board's mercury TMDL can be obtained from http://www.waterboards.ca.gov/sanfranciscobay/TMDL/sfbaymercurytmdl.htm, last accessed on 8/16/2007.

Selenium

CALFED BAY-DELTA PROGRAM

Problem

Selenium is a dietary requirement in most higher organisms, but can also bioaccumulate to levels that threaten the health of wildlife species, their predators, and their consumers. In the San Francisco Bay-Delta, the resource issue at stake is the health of fish that forage the bottom, especially sturgeon. Bottom dwelling invertibrates such as the Dungeness crab may also be at risk. Right now, selenium concentrations in sturgeon are just above the monitoring threshold of 5.9 µg/g. While these concentrations are below the current USEPA standard of 7.9 µg/g, there is substantial scientific evidence indicating that this standard is not protective enough and more stringent standards for the Bay-Delta are being considered. As discussed below, some industrial point sources of selenium have been reduced during the last decade. However, changes in the food web (specifically, invasion of the Asian clam *P. Amurensis*) and the potential for increased loads from agricultural sources mean that the future of the sturgeon as a viable fisheries resource is still at risk.



The main sources and chemical forms of selenium that discharge to the San Francisco Bay – Delta. Oil refinery discharges, which have been dramatically reduced, are predominantly selenite (a form with higher ecological risk). Agricultural drainage is predominantly selenate, a form with lower ecological risk. Water management and drainage choices will play a critical role in the future of selenium loadings to the Bay. **Figure modified from Abusaba and Ogle (2005).**

Sources and Causes

Selenium is a naturally occurring trace element that shares many chemical properties with sulfur. The soils and the shale oils of the San Joaquin Valley contain selenium as a result of the pre-historic presence of an inland sea. Selenium is mobilized primarily by two human activities, both of which have seen dramatic reductions over the past decade. Oil refining mobilizes selenium during the sulfur removal process, creating elevated selenium concentrations in oil refinery discharges. Irrigated agriculture mobilizes selenium from the selenium-rich soils in the western San Joaquin Valley, and it accumulates to potentially harmful levels in the tile drainage water from that area. The presence of selenium makes drainage management in these areas considerably more difficult.

Selenium bioaccumulation in organisms is further complicated in that some forms of selenium have a much greater tendency to accumulate than others. The form of selenium most common in agricultural drainage is selenate, the chemical analogue of sulfate. Of all the forms of selenium, selenate has the lowest ecological risk of bioaccumulation and toxicity, and is mitigated by sulfate, which is taken up by the same mechanisms.

Selenate can be converted to selenite in chemically reducing environments, such as wetlands and organic-rich, stagnant waters. Selenite is bioaccumulated much more readily than selenate. Selenite is the form of selenium most common in refinery discharges. Selenate and selenite taken up by terrestrial and aquatic plants is incorporated into proteins by substitution for sulfur amino acids. This “bio-transformation” leads to the many different forms of “organo-selenium,” which pose the greatest ecological risk. In terms of the accumulation in filter feeders like clams, organo-selenium attached to particles appears to be the most problematic. This is important because there is evidence that sporadic inputs of particulate organoselenium from the Delta may be initiated by water management activities.

Geographic Extent

The main areas of concern for selenium impairment within the Delta are in the northern reach of San Francisco Bay and Suisun Bay. The Sacramento and San Joaquin Rivers are the two largest rivers contributing to the Delta. The San Joaquin River experiences higher concentrations of selenium than the Sacramento River, yet flows in the Sacramento River dwarf flows coming from the San Joaquin River, an important factor when considering selenium loading.

Selenium is more likely to accumulate in Suisun Bay than the Delta due primarily to food web complexity. The magnification of bioaccumulative pollutants like selenium and mercury is greatest in complex food webs. The food web of Susiun Bay tends to be more complex, i.e., there are more trophic levels and interconnections, than in the Delta.

Similarly, while portions of the San Joaquin River watershed produce elevated selenium concentrations in surface water, the selenium is in the selenate form. The primary concern with food chain exposure tends to be downstream of source waters, where selenium is transformed from selenate to selenite and bioaccumulated. As a protective measure, the State Water Board regulates the discharge of selenium from agricultural drainage, and current monitoring studies are under way to evaluate whether selenium in the food chain is a problem in these upstream watersheds.

Sporadic inputs of particulate selenium from the Delta to the northern reach of the San Francisco Bay were discovered recently. These are likely caused by episodic discharges in this area, which has complex circulation. These inputs need to be investigated further.

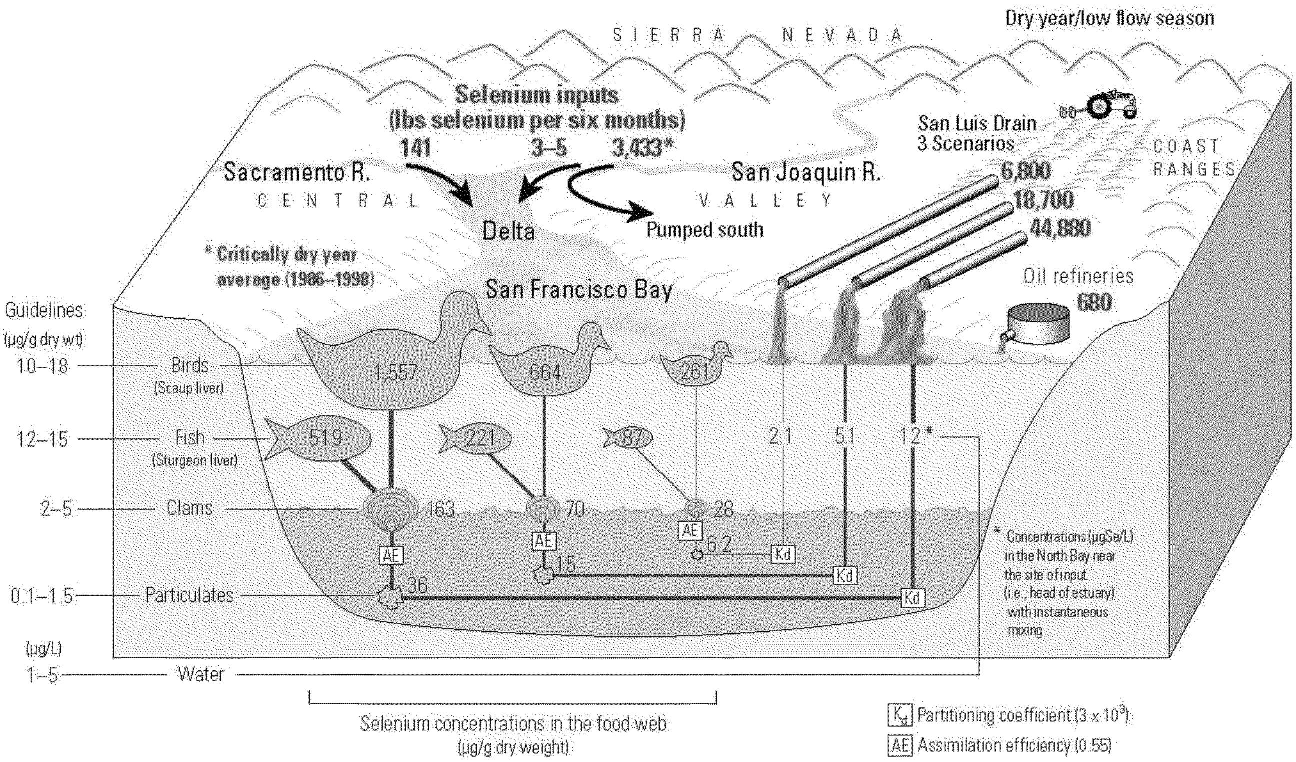
Conceptual Model

The conceptual model for selenium has evolved over time in three stages. In the early 1980s, little was known about selenium in the Bay-Delta ecosystem. When high selenium concentrations were observed in diving ducks and sturgeon in the Delta, the initial conceptual model focused on agricultural drainage discharges, based on the experience in the San Joaquin River watershed. Over a ten-year period, a local source of bioavailable selenium (selenite) was traced back to the Bay Area oil refineries. The conceptual model evolved to a second phase, incorporating these newly identified sources, with particular attention on the more bioavailable form of selenite. Based on this understanding, The San Francisco Bay Water Board compelled the refineries to reduce their selenium loads. In the third phase, after load reductions by the refineries, the selenite peak disappeared, but monitoring still showed contamination problems in the food web. The new conceptual model noted the reductions from refineries, but focused on changes in the food web and selenium releases from agricultural sources as contributing to the continuing selenium issue.

Corrective Actions

Load reductions from point sources to the San Francisco Bay and nonpoint sources to the San Joaquin River have been successful, and there is some progress at the federal (EPA / USFWS) level in the area of standards development. USEPA national and state actions will set fish tissue concentration goals that are protective of ecosystem health.

Management questions that will need to be addressed when implementing the new fish tissue criterion include:



The figure above, from Presser and Luoma (2007), shows how tissue concentrations of ducks, fish, and clams are forecast to respond to different selenium loading scenarios from the San Luis Drain. The forecast scenarios for low flow conditions during a dry year are compared to risk assessment guidelines.

- What is the most appropriate way to dispose of agricultural drainage from high-selenium areas?
- Given that wetlands can biotransform selenate to forms having higher risk, how can we protect ecosystem restoration projects from high-selenium waters?
- How will water conveyance decisions affect movement of selenium into and out of ecologically sensitive areas?
- Are further point source reductions needed in Suisun Bay?

A current action path being investigated is providing drainage service to agricultural operations in the San Joaquin Valley. Drainage service, while necessary to ensure the long-term sustainability of these lands for agricultural production, was stopped due to selenium effects on waterfowl. The San Luis Drain Reevaluation was completed recently by the USBR and recommended "in-valley" disposal as a preferred alternative for a drainage solution. However, that solution may conflict with regional strategies to manage salt accumulation in the Central Valley. One potential solution under investigation is an arrangement to transfer the USBR responsibility of managing drainage to the Westlands Irrigation District. This would have the benefit of moving accountability for drainage management to landowners that are more directly regulated by the CVRWQCB. Such an action may also point more to an in-valley solution. Regardless of the outcome of that decision, dischargers of selenium-laden agricultural drainage will need to meet a 5 ug/L objective in tributaries to the San Joaquin River by October 2010.

Next Steps

A massive amount of selenium exists in the soils of the western San Joaquin Valley. Consequently, the key issue is transport of this selenium from the San Joaquin Valley through the Delta and into the Bay. Recent water conveyance proposals could have the net result of moving greater amounts of selenium into the Bay–Delta because of increasing flow proportions from the San Joaquin side and/or decreasing flow proportions from the Sacramento side. As with mercury concerns, thorough analysis and review will be required to assess the effects of any major water conveyance or storage projects. Monitoring is also needed, to detect potential risks resulting from selenium loads and to further refine our understanding of the problem. Finally, a commitment to action is needed to respond to risk indicators if they are triggered.

Next steps that were specifically highlighted by experts interviewed for this fact sheet include:

- Supporting USEPA's development of a tissue-based standard for selenium;
- Supporting the SWRCB development of an implementation plan for a USEPA promulgated standard;
- Ensuring that peer research and monitoring reports directed at solutions undergo thorough external scientific peer review;
- Providing adequate funding for monitoring to detect threats to the ecosystem as a result of decisions about drainage service, water conveyance and storage, and ecosystem restoration; and
- Establishing a commitment to take clearly defined actions if monitoring detects significant threats.
- Supporting the initiative by the Central Valley Water Board to find a solution to the salt problem in the Central Valley, an issue which is directly linked to the selenium issue of agricultural drainage

For more information

This fact sheet was developed based on an interview with Dr. Samuel N. Luoma of the United States Geological Survey. Dr. Luoma has a B.S. and an M.S. in Zoology from Montana State University, and a Ph.D. in Marine Biology from the University of Hawaii. He is a Senior Research Hydrologist with the US Geological Survey. Since 2000 he has served as the first Lead Scientist for the CALFED Bay-Delta program. His specific research interests are in the bioavailability and effects of pollutants in aquatic environments and developing better ways to merge environmental science and policy. He is an author of more than 160 peer-reviewed publications. He wrote the textbook *Introduction to Environmental Issues* in 1984; is an editorial advisor for the highly respected *Marine Ecology Progress* series; and is editor of *Marine Environmental Research*.

The interview was supplemented with the following citable sources to develop this fact sheet:

Presser, T. and S. N. Luoma (2007). "Forecasting Selenium Discharges to the San Francisco Bay-Delta Estuary: Ecological Effects of a Proposed San Luis Drain Extension." United States Geological Survey, Water Resources Division, Menlo Park, California. Professional Paper #1646. Available at http://pubs.usgs.gov/pp/p1646/ .

Abusaba, K.E. and Ogle, S. (2005). *Selenium in San Francisco Bay: Conceptual Model Impairment Assessment Report*. Prepared on behalf of the Clean Estuary Partnership, Oakland, California. Available at http://www.cleanestuary.com.

Linville, R. G., S. N. Luoma, et al. (2002). "Increased selenium threat as a result of invasion of the exotic bivalve Potamocorbula amurensis into the San Francisco Bay-Delta." *Aquatic Toxicology* 57(1): 51-64.

Purkerson, D. G., M. A. Doblin, et al. (2003). "Selenium in San Francisco Bay Zooplankton: Potential Effects of Hydrodynamics and Food Web Interactions." *Estuaries* 26(4): 956-969.

Stewart, A. R., S. N. Luoma, et al. (2004). "Food Web Pathway Determines How Selenium Affects Aquatic Ecosystems: A San Francisco Bay Case Study." *Environmental Science. and Technology* 38(17): 4519-4526.

Web resources

Information on current regulatory approach to managing selenium loads in the San Joaquin River is available on the CVRWQCB website, last accessed on 7/2/2007:

http://www.waterboards.ca.gov/centralvalley/programs/tmdl/selenium.htm

Information on regulatory concerns about selenium accumulation in watersheds of the San Joaquin River can be found in the Grasslands Marshes Selenium TMDL, which is also available on the CVRWQCB website, last accessed on 7/2/2007:

http://www.waterboards.ca.gov/centralvalley/programs/tmdl/grasslands-se/index.html

Monitoring information from the Grasslands area is available from the United States Geological Survey, last accessed on 7/2/2007:

http://wfrc.usgs.gov/research/contaminants/STSaiki4.htm

The environmental documentation for the San Luis Drain reevaluation can be found at the USBR website at, last accessed on 7/2/2007:

http://www.usbr.gov/mp/nepa/nepa_projdetails.cfm?Project_ID=61

A presentation on the outcome of the San Luis Drain reeavaluation is available on the CALFED website at, last accessed on 7/2/2007:

http://calwater.ca.gov/BDPAC/Subcommittees/DrinkingWater/DWQP_Meeting_Notes_7-22-05/San_Luis_Drainage_7-22-05.pdf

The USEPA position on the San Luis Drain reevaluation can be found at, last accessed on 7/2/2007:

http://www.epa.gov/region09/nepa/letters/san-luis-deis-re-evaluation.pdf

USFWS concerns over re-opening the San Luis Drain are summarized at, last accessed on 7/2/2007:

http://www.fws.gov/pacific/ecoservices/envicon/pim/reports/Sacramento/San%20Luis.html

Information on the Orange County Nitrogen Selenium Management Program can be found at: www.ocnsmp.com, last accessed on 7/2/2007

Pesticides

CALFED BAY-DELTA PROGRAM

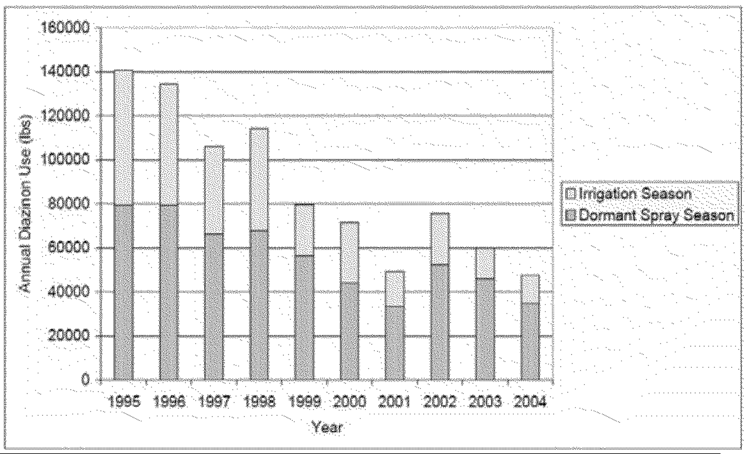
Problem

A pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. Though often misunderstood to refer only to insecticides, the term pesticide also applies to herbicides, fungicides, and various other substances used to control pests. The pesticides of concern in the Delta are primarily insecticides but herbicides are also frequently detected.

In the Bay-Delta region, the known pesticides of concern include diazinon, chlorpyrifos, pyrethroids, and the legacy organochlorine pesticides although any pesticide that contributes to water column or sediment toxicity is potentially of concern. These substances are known to have adverse impacts on aquatic organisms or, in the case of the organochlorine pesticides, birds and mammals. Studies in the mid-1990 showed that two commonly used organophosphorus pesticides, diazinon and chlorpyrifos, can have acute affects on aquatic organisms. A number of pesticides that came into wide-spread use in the 1980's appeared in Central Valley waterways particularly during periods of high winter flows. Monitoring in the the early 1990s confirmed the presence of diazinon and chlorpyrifos at levels of concern in Delta waters.

Diazinon and chlorpyrifos have caused acute toxicity to aquatic organisms (primarily small crustaceans) in tests of Delta surface water. The pyrethroid pesticides, common replacements for the now more tightly regulated diazinon and chlorpyrifos, accumulate in sediment and can impact bottom dwelling organisms. The legacy organochlorine pesticides, like DDT and related compounds, bioaccumulate in aquatic food chains.

Pesticides that bioaccumulate may affect species at the top of the food chain by hindering natural survival activities, such as avoiding predators or fighting off disease. Exposure to pesticides for extended periods of time may have long term effects, such as developmental problems.



Annual agricultural use of diazinon has declined with increased regulation and shifts to alternative pesticides. (CVRWQCB 2007)

Sources and Causes

Pesticides are applied in both urban and agricultural settings, to control insects and other pests. Pesticides move through the air and are mobilized by irrigation water and stormwater. Some pesticides adhere to and are transported with sediment. Pesticides enter watershed creeks, canals, and rivers, and Delta waterways through rainfall, stormwater runoff and irrigation return flows.

Geographic Extent

The Sacramento, San Joaquin, and Feather Rivers, the Delta, and numerous agriculturally dominated streams in the Central Valley are either listed as impaired or are currently covered under an existing Total Maximum Daily Load (TMDL) for pesticides. Smaller agriculturally dominated waterways are particularly vulnerable to toxicity from pesticides. Although agriculture is considered the primary source of pesticide impairment in the Central Valley and Delta, urban sources are also locally important. Some of the highest pesticide concentrations have been observed in urban creeks and sloughs receiving urban runoff.

Wherever monitoring has been done on urban creeks in the Central Valley pesticides or their effects have been observed. Most of this monitoring has been done in Stockton and Sacramento so most of the listings of impaired water bodies are in these metropolitan areas. This is similar to the pattern observed in the more heavily urbanized San Francisco Bay Area where a pesticide TMDL covers all urban creeks.

Conceptual model

Along with the location and manner of use, the physical and chemical properties of pesticides determine their distribution and effects in the environment. A small fraction of the pesticides applied to agricultural land and urban areas finds its way into runoff and irrigation return flows. The water then runs off into urban or rural streams, canals, or other waterways, and then flows into and through tributary streams and the Delta. Pesticide impairment is more likely in the smaller streams and water bodies closest to the source.

Contamination of surface waters can occur even if all directions and rules for application are followed. Pesticides can volatilize into the air and may then be picked up by rainfall. Pesticides on plants, soil, and other surfaces can be washed off by rain or subsequent irrigation. Pesticides adhering to soil particles can be carried downstream by erosion.

The biological effects of a pesticide are a function of its chemical properties, exposure to the pesticide, and the physiology of the organism. Organisms vary widely in the susceptibility to the toxic effects of pesticides. Small crustaceans and aquatic insects tend to be the most vulnerable to insecticides. Toxicity means any observable adverse effect on an organism. In aquatic toxicity tests this can be mortality (acute toxicity) or other effects such as reduced reproduction or growth (chronic toxicity).

Pesticides vary in their affinity for particulate matter, solubility, and their lifetime in the environment. For example, diazinon is relatively soluble in water, does not adhere strongly to sediments and is not particularly persistent in the environment. It is commonly found in the water column within a few days or weeks of application. Diazinon and related pesticides are frequently associated with observed water column toxicity to aquatic crustaceans. Pyrethroid pesticides have a high affinity for sediment and so have been identified as the cause of toxicity to bottom dwelling organisms. Some pyrethroid pesticides are also highly toxic to fish.

The now banned organochlorine pesticides such as DDT and chlordane are nearly insoluble in water and adhere tightly to soil particles. They have a strong tendency to bioaccumulate through the food chain. Although it was taken off the market in 1972, DDT is still found in sediments, fish, and human tissue samples. DDT is known to have adverse effects on animal reproduction and is a probable human carcinogen. Although ubiquitous in sediments and commonly found in fish and animal tissues, these legacy pesticides are generally not found at harmful levels in the Delta.

In addition to the mortality, reproductive and growth effects, and carcinogenicity, pesticides can have other adverse effects on aquatic organisms. Toxic substances can reduce the physical performance of organisms, such as swimming ability, and can affect behavior. For example, recent studies have shown that very low concentrations of some pesticides can impair the sense of smell of salmon. The chronic low level effects of pesticides on fish populations are not well understood.

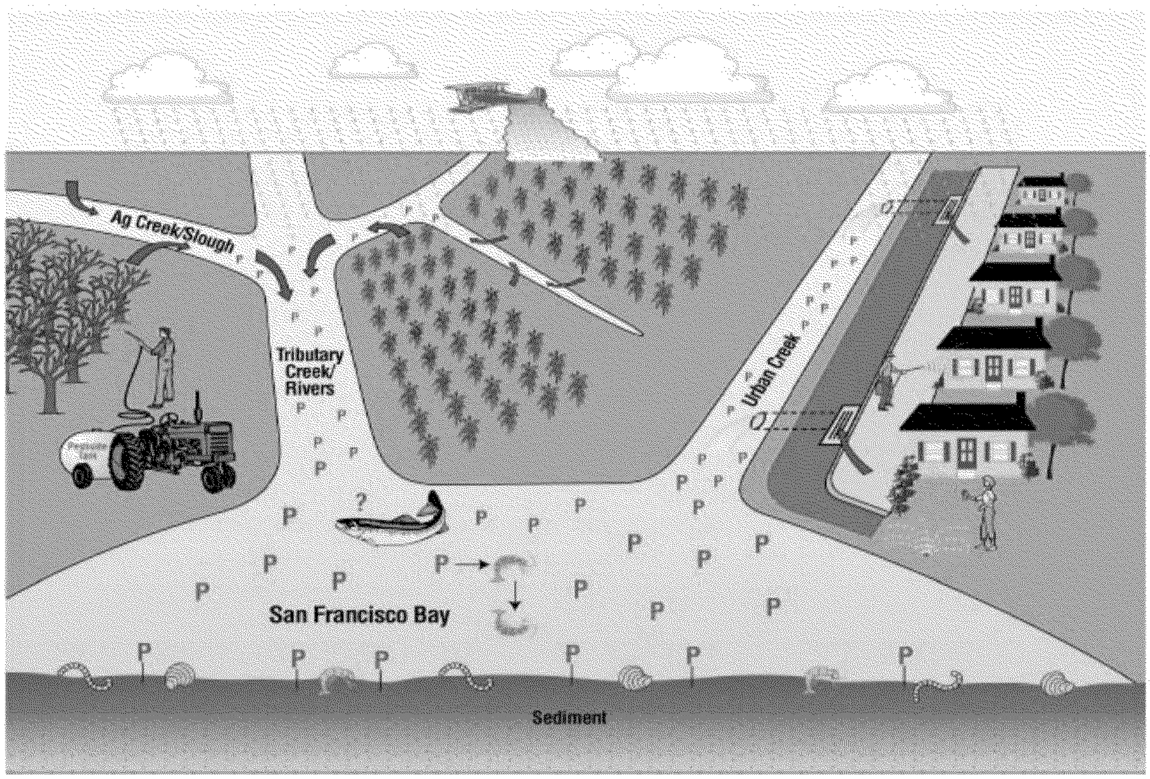
Corrective Actions

The identification of toxicity in ambient waters associated with diazinon and chlorpyrifos, previously two of the most widely used agricultural and household insecticides, lead to the regulatory actions by the SWRCB and RWQCB. TMDL's are used to amend basin plans to regulate pesticides and other pollutants. Since pesticide sale and use in California is under the control of the Department of Pesticide Regulation (DPR), the Central Valley Regional Water Quality Control Board and DPR have worked together to develop pesticide control programs. These programs have resulted in the placing of additional instructions for best management practices in the labeling for the several pesticides. Research, outreach, and education through CALFED funded projects and other agencies such as the UC Cooperative Extension and county agricultural commissioners are helping farmers and homeowners to reduce pesticide pollution.

At the national level, the EPA has also taken action to reduce water pollution by diazinon and chlorpyrifos. Both pesticides now have a reduced list of approved agricultural uses and diazinon has been removed entirely from household pesticide products.

The Irrigated Lands program established a discharge permit waiver for agricultural dischargers who voluntarily join a coalition groups. The program requires that the coalitions monitor and report on the condition of their receiving waters. The individual farmers and coalitions are also required to implement feasible management practices to prevent water quality impacts and to take corrective action if monitoring indicates a problem.

The current regulatory framework appears to have functioned reasonably well in dealing with identified pesticide problems. Recent studies have shown a significant drop in diazinon and chlorpyrifos use and ambient



concentrations (CVRWQCB 2006). The magnitude, occurrence, and duration of toxicity due to diazinon and chlorpyrifos have also decreased considerably since the early 1990s.

Although diazinon and chlorpyrifos use has decreased, it appears that growers have shifted to other pesticides. The use of pyrethroid pesticides in agricultural and household products has increased.

The Interagency Ecological Program has performed extensive toxicological testing in and attempt to determine the cause of the historically low levels of pelagic fish species. In contrast to monitoring in the early 1990s which frequently found 100% toxicity to test organisms in the San Joaquin and Sacramento Rivers, monitoring in the last few years has found only occasional and low levels of toxicity. The evidence that toxicity from pesticides (or other contaminants) is a significant contributor the current decline in Delta pelagic fish species is still inconclusive (Armor et al, 2005).

Next Steps

New pesticides are continually entering the market and research on the effects of pesticides on aquatic life continues to give reason for concern about pesticide impacts. The CVRWQCB is developing a TMDL and Basin Plan Amendment that will cover all pesticides in the Delta and its Central Valley tributaries. This will forego the arduous individual pesticide compound regulatory approach used in the past.

The CALFED agencies should continue to work through the existing Irrigated Lands and Stormwater programs to monitor for potential pesticide impairment associated with these non-point sources. The SWRCB and RWQCB should also continue to work with the DPR and EPA to prevent pesticide impairment through the pesticide use regulatory processes.

The CALFED agencies should continue to support and possibly expand the current level of IEP pesticide and toxicity monitoring. Toxicity is often short-lived and may not be captured by a low frequency monitoring program. It is also essential that a sufficient level of funding be continued for assessment and research into the linkage between water quality and population level effects like the Pelagic Organism Decline.

For More Information

This fact sheet was developed based on interviews with Dr. Inge Werner of the Department of Anatomy, Physiology and Cell Biology, School of Veterinary Medicine, University of California, Davis and Joe Karkoski, staff of the Central Valley Regional Water Quality Control Board for seven years.

Dr. Werner has a Ph.D. in Zoology and Toxicology from the University of Mainz, Germany; an M.S. in Limnology from Universities of Freiburg, Germany; and has conducted Post-doctorate research in Aquatic Toxicology at the University of California, Davis. Her research and publications focus on aquatic toxicology, organophosphorus pesticide toxicity and its effect on fish and on alternative practices for reducing pesticide impacts on water quality.

Mr. Karkoski holds a B.S. in Chemical Engineering from Michigan State University. His focus is on permitting specifically Total Maximum Daily Loads (TMDL) and pesticides in the Sacramento and San Joaquin River valleys. He deals with the use of basin plan amendments for point and non-point sources of pesticides.

The following sources were also used to develop this fact sheet:

C. Armor, R.Baxter, B. Bennett, R. Breuer, M. Chotkowski, P. Coulston, D. Denton, B. Herbold, W. Kimmerer, K. Larsen, M. Nobriga, K. Rose, T. Sommer, and M. Stacey. 2005. Interagency Ecological Program Synthesis of 2005 Work to Evaluate the Pelagic Organism Decline (POD) in the Upper San Francisco Estuary. Interagency Ecological Program.

Central Valley Regional Water Quality Control Board. 2006. Amendments to the Water Quality Control Plan For the Sacramento River and San Joaquin River Basins For The Control of Diazinon and Chlorpyrifos Runoff into the Sacramento-San Joaquin Delta. June 2006 Final Staff Report

Smalling, K.L., J. L. Orlando, K.M. Kuivila. 2007. Occurrence of Pesticides in Water, Sediment, and Soil from the Yolo Bypass, California. San Francisco Estuary and Watershed Science.

San Francisco Bay Regional Water Quality Control Board. 2005. Diazinon and Pesticide-Related Toxicity in Bay Area Urban Creeks, Water Quality Attainment Strategy and Total Maximum Daily Load (TMDL), Proposed Basin Plan Amendment and Staff Report.

Web resources

Information on the CVRWQCB TMDLs including the Central Valley pesticide TMDL project.
http://www.waterboards.ca.gov/centralvalley/programs/tmdl/pest-basinplan-amend/index.html

Information on the UC Integrated Pest Management program.
http://www.ipm.ucdavis.edu/

Information on the SFBRWQCB urban creeks pesticide TMDL.
http://www.waterboards.ca.gov/sanfranciscobay/TMDL/urbancrksdiazinontmdl.htm

Information on the Pelagic Organism Decline studies.
http://science.calwater.ca.gov/pod/pod_index.shtml

Toxicity of Unknown Origin

CALFED BAY-DELTA PROGRAM

Problem

The presence of toxic substances in the Delta and the Sacramento and San Joaquin Rivers is of concern with respect to the health of the ecosystem. Toxicity events can kill aquatic species and reduce or eliminate the food supply of many fish species.

The term "unknown toxicity" refers to toxicity in a water sample that has not been linked to specific chemicals. Depending on the test type and species, the determination of toxicity generally includes mortality, reduced growth, or reduced reproduction for a specific aquatic organism exposed to a water sample over a standard duration of time.

Toxicity is determined through rigorous laboratory procedures using standard USEPA methods. Under the CALFED Bay-Delta Program, the process of aquatic toxicity testing begins by collecting samples at strategically selected monitoring sites. In a laboratory setting, specific test species (a minnow, a small crustacean, and a water flea) are exposed to the samples for seven to ten days to determine the effects of the sample water on the test organisms. The number of fatalities within the test species population is observed and recorded. For a sample to be reported as toxic, a reduction in the test species' survival (and in some cases, growth or reproduction) observed must be statistically significant as compared to a laboratory control sample.

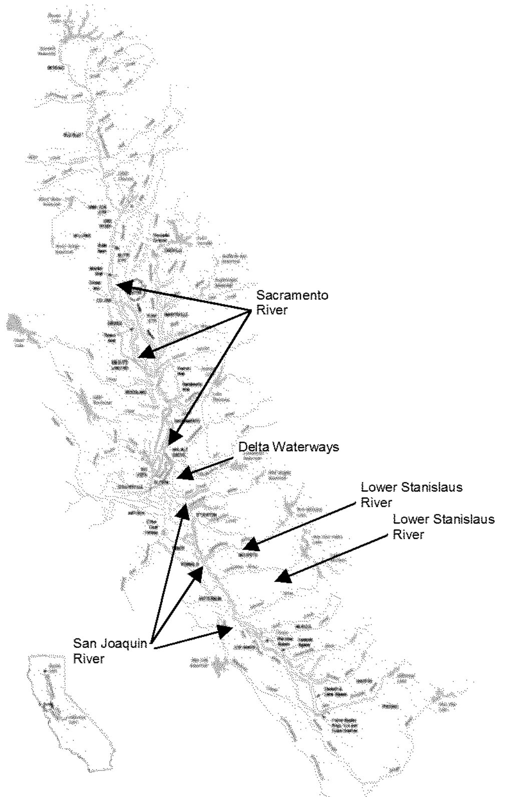


Figure 1: Water Bodies on the 303(d) List for Unknown Toxicity Impairment

Causes of aquatic organism mortality are oftentimes initially unknown. Numerous chemicals and physical stressors in water can contribute to mortality, making it difficult to assess the direct cause of death. Two factors that further complicate the determination of the cause include: (1) additive toxicity can result from the presence of more than one toxicant and (2) toxicants may be diluted in larger water bodies.

Currently, large portions of the Sacramento and San Joaquin Rivers are impaired and are included on the Clean Water Act Section 303(d) list for unknown toxicity. These stretches are denoted on figure 1. These rivers receive agricultural and urban storm runoff, a wide variety of human-related and natural stressors, including toxicants, are found in these waters.

Sources and Causes

Known sources of toxicity are numerous and varied. With increased anthropogenic influences in the watershed, aquatic habitat has become more exposed to toxicity from various sources. Alteration of natural flow patterns and land uses has added new sources of natural and artificial toxicants to existing aquatic habitats.

As urban and agricultural runoff flows over land, it can transfer numerous compounds to the ecosystem, including toxic pesticides and metals.

Flow alteration and naturally occurring elements may also contribute to toxicity. When dredging or altering flow patterns, sediment can re-suspend, which can be problematic if a toxicant is bound to the sediment. Some heavy metals (e.g., mercury) and pesticides (e.g., pyrethroids) are examples of toxicants that commonly bind to sediment.

Geographic Extent

Evidence of toxicity has been found in water bodies throughout the Delta waterways and the Sacramento and San Joaquin River Basins. The toxicity signal in agriculturally dominated upstream creeks and streams is typically amplified because toxic compounds are higher in concentration. Dilution in the larger water bodies (e.g. Sacramento River and San Joaquin River) has the potential to buffer the effects of the numerous toxicants.

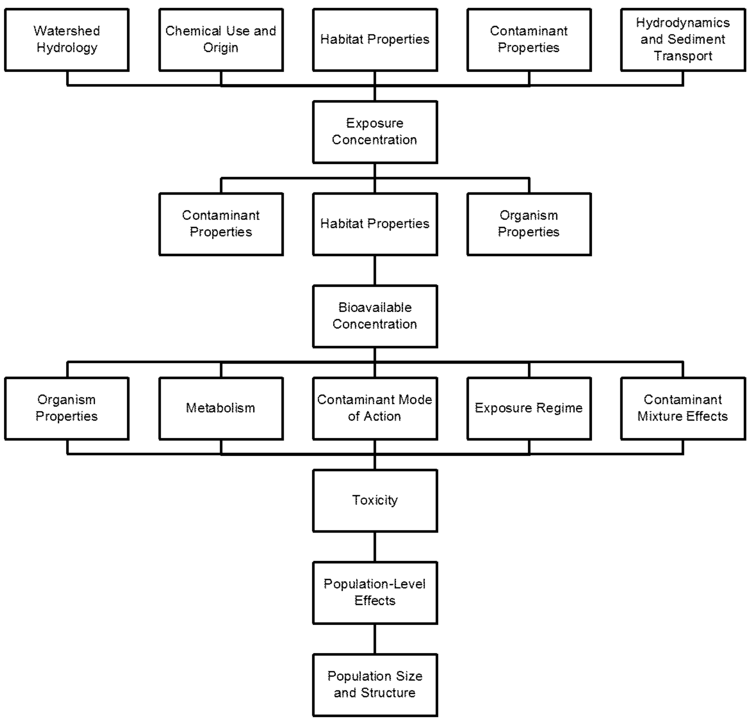
Conceptual Model

The concentration of a contaminant to which an aquatic organism is exposed (i.e., exposure concentration) is driven by watershed hydrology, chemical use and origin, habitat properties, contaminant properties, and hydrodynamics and sediment transport. Among these, only the watershed hydrology cannot be controlled in some way. However, one cannot determine the toxicity of a contaminant or mixture of contaminants using measurements of the exposure concentration alone because toxicity depends on how much of a contaminant is available for the organism to take up (i.e., bioavailable concentration). The bioavailable concentration of a contaminant depends on the contaminant properties, organism properties, and the properties of the habitat in which the organism lives. Once the organism uptakes the contaminant, organism properties, metabolism, the contaminant's mode of action, the exposure regime and effects of contaminant mixtures ultimately determines the toxic effects at the individual level. Depending on the degree of effects at the individual level, there could be population effects that then drive the population size and structure.

Corrective Actions

While toxicity is still present within the Delta and many of its tributary water bodies, some existing toxicants have been identified, which has allowed for direct, proactive action. Currently, the most important corrective action is further understanding of toxicity sources in the Delta. There is need for a sustained, comprehensive contaminant and toxicity monitoring program in the Delta.

The State of California provides the majority of the funding for toxicity studies within the Bay-Delta Region. Recently, the Delta Pelagic Organism Decline (POD) has highlighted the concern over toxicity within the Delta. In response to the observed decline of the native fish species within the Delta, the POD has funded more Delta toxicity studies.



Data gathering is essential for uncovering the cause of unknown toxicity. Increased monitoring within the Delta and San Joaquin and Sacramento Rivers has begun to take place. As an example, the Central Valley Regional Water Quality Control Board manages the Irrigated Lands Conditional Waiver (Ag Waiver) Program, which requires water quality monitoring of agricultural discharges in the Central Valley. The data generated by the Ag Waiver Program indicates that there is acute toxicity in the Delta and upstream tributaries; however, there has been only limited success in identifying the cause.

While the methods for identifying toxic events are adequate, agencies are addressing toxicology methods to improve accuracy and reliability of the toxicity testing. Particular issues of concern with current methods include: (1) results of tests using indicator species cannot be directly related to effect on populations of species of concern, such as the Delta smelt, and (2) the ability to determine the cause of toxicity is limited by loss of toxicity in a sample and inconclusive toxicity identification evaluations. Corrective actions to address these issues will increase the reliability and effectiveness of toxicity testing.

Next Steps

Consistent funding for a comprehensive monitoring program would allow for identification of toxic events and causes quickly allowing the agencies to address the root causes of ecosystem toxicity.

Of great concern is the effect pollutants may have which may not yield identifiable toxic events. Exposure to certain pollutants causes sub-lethal effects, such as decreased predator avoidance or immune system suppression; these effects are not addressed in the regulatory framework and may have significant effects on fish populations. Studies undertaken by the Pelagic Organism Decline program have shown little direct toxicity within the delta; however, toxicants may still play a role by reducing their survivability within the ecosystem. Long term and sub-lethal affects are important for the survival of fish species and need to be better understood and addressed when determining ecosystem heath. The State and Federal agencies should continue to support research on the role of toxics in Delta ecosystems.

For More Information

This fact sheet was developed with the help of Dr. Inge Werner of the Department of Anatomy, Physiology and Cell Biology, School of Veterinary Medicine, University of California, Davis of UC Davis, Karen Larsen of the Central Valley Regional Water Quality Control Board, and Dr. Bruce Herbold of the USEPA

Dr. Werner has a Ph.D. in Zoology and Toxicology from the University of Mainz, Germany; an M.S. in Limnology from Universities of Freiburg, Germany; and has conducted Post-doctorate research in Aquatic Toxicology at the University of California, Davis. Her research and publications focus on aquatic toxicology, organophosphorus pesticide toxicity and its effect on fish and on alternative practices for reducing pesticide impacts on water quality.

Dr. Herbold received his BA from UC Berkeley, an MS from California State University Los Angeles and his Ph.D from UC Davis. His research has focused on native and introduced fish species in Suisun Marsh and the Delta. He has done work for the San Francisco Estuary Project and with the CALFED Bay-Delta Program. His duties at USEPA have included the development of water quality standards and studying the impacts of water operations on Delta fish.

References:

USEPA, 2002. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Fourth Edition. United States Environmental Protection Agency. October 2002. http://www.epa.gov/region6/water/npdes/wet/wet_methods_manuals/ctf.pdf

Drinking Water

CALFED BAY-DELTA PROGRAM

Problem

The Delta is used as a drinking water supply, either solely or partially, for over 23 million Californians. For the past 50 years, the Delta has been operated as a water supply system, transporting natural and stored flows to two major Delta intakes and several minor intakes. Regulation of drinking water quality has also evolved over this time period, from a focus on the removal of turbidity and disinfection of bacteria to a focus on the removal of contaminants, disinfection of a broader spectrum of microbials, and control of harmful byproducts of the disinfection process.

The Delta periodically contains significant concentrations of the precursors – bromide and organic carbon – that can lead to the formation of regulated disinfection byproducts. Many treatment plants have made expensive adjustments so that they can continue to treat Delta water, but degradation of Delta water quality would result in exponentially higher treatment costs.

Sources and Causes

Bromide and organic carbon come from two distinct sources. Bromide comes from seawater and organic carbon comes from a variety of anthropogenic and natural watershed sources. In addition to these precursors, pathogens, nutrients, algae, and turbidity are also concerns to drinking water. Pathogens trigger disinfection requirements, turbidity affects filtration processes, and nutrients and their resultant algae blooms disrupt treatment processes and cause taste and odor problems.

Management of the Delta for water supply is complicated because of the estuarine dynamics, resulting in periodic seawater intrusion at intakes. Both salinity and bromide largely originate from this seawater intrusion, with salinity concentrating within the watershed through agricultural, wetland, industrial and residential water use. Seawater intrusion is repulsed by freshwater flows, provided either naturally through precipitation or manipulated and regulated through upstream reservoir releases. The channel geometry and bathymetry of the Delta also play a significant role in how seawater reaches Delta intakes.

The remainder of the drinking water constituents of concern - organic carbon, nutrients, algae, and turbidity – originates in the watershed of the Delta. Sources include agriculture, wetlands, municipal wastewater, urban stormwater, forest management and fires, and natural processes – slope, soil types, and precipitation. On average, the highest concentrations come from the San Joaquin River within and from within the Delta, but spikes in concentration can originate in the Sacramento River watershed. These sources arrive at Delta intakes in slightly different proportions, based on the location of the intake, the relative amounts of inflow, and other hydrodynamic factors.

There are hundreds of small, medium, and large systems that treat Delta water, and many systems wholesale treated water to other agencies. Of the 37 systems identified by the CALFED Water Quality Program, the majority use conventional treatment processes and chlorine as a disinfectant. Chlorination, with the levels of precursors in Delta water, results in high levels of disinfection byproducts known as trihalomethanes.

As regulation of trihalomethanes has increased, larger treatment plants have moved to alternative treatment and disinfectants to reduce levels of trihalomethanes. One alternative disinfectant employed by a handful of plants is ozone, which does not form trihalomethanes but does form bromate in the presence of bromide, another harmful byproduct. As more plants move towards employing ozone, bromide increases in importance as a priority constituent of concern.

There are other constituents that may become a concern for drinking water quality, but have not risen to a priority within the CALFED program. This is mostly due to a lack of data within the watershed or at treatment plants, a lack of occurrence at levels of concern at treatment plants, a lack of information on public health data, or because the constituent is being adequately assessed or regulated through other programs.

Geographic Extent

Although the drinking water constituents of concern can come from anywhere in the Delta watersheds, the most significant increases occur below the large tributary dams. Major Delta intakes are located in the southwestern Delta; other intakes are located in the western Delta, and in the northern Delta. There are also three planned intake relocation projects, moving into the Central Delta and Sacramento River. Delta water is then conveyed to treatment plants throughout the central and southern coastal and central valley areas of California. This conveyance occurs through open air aqueducts and pipelines and can be stored in reservoirs of various sizes. Drinking water quality is different than ecosystem water quality because of the transportation and processing of the water prior to its beneficial use.

Conceptual Model

Conceptual models have been developed for drinking water quality as a whole, and for salinity, organic carbon, nutrients, and pathogens in the Delta and its watershed. The watershed conceptual models include literature searches, data collection and analysis, and recommendations for future work and can be found on the Central Valley Regional Water Quality Control Board (CVRWQCB) website for the Central Valley Drinking Water Policy.

The United States Geological Survey has also developed conceptual models for organic carbon associated with certain land uses. The CALFED Water Quality Program is pulling together all information into one overall conceptual model, from the watershed through to treatment, within its Final Stage 1 Assessment Report, scheduled for release in September 2007.

Corrective Actions

The CALFED Record of Decision identified several actions for implementation during Stage 1, including source improvement and regulation, conveyance watershed improvement, water quality exchanges, drainage relocation, and treatment studies. The funding for implementing these actions fell significantly short.

The CALFED Water Quality Program target for bromide is a running annual average of 50 µg/L or an equivalent level of public health protection in treated water. It is not possible to achieve this target solely in the Delta with continued through Delta conveyance, current averages at the intakes range from 89 to 424 µg/L, so actions have focused on treatment and infrastructure changes as well.

The largest in-Delta improvement potential is through CALFED Conveyance Program projects – reoperation of the Delta Cross Channel, reconfiguration of Franks Tract, and/or construction of a new intake at Hood for conveyance of Sacramento River water to the interior Delta (Through-Delta Facility). New storage projects are also being studied for potential drinking water quality benefits.

The WQP funded the relocation of two Delta drains to improve Contra Costa Water District's intake water quality, projects to reduce salinity discharges into the San Joaquin River, and studies of bromate suppression technologies. There is still much to be done to prepare for the anticipated stricter regulation of bromide-related disinfection byproducts.

The CALFED Water Quality Program target for organic carbon is a running annual average of 3 mg/L or an equivalent level of public health protection in treated water. Running annual averages at the Delta intakes range from 2.7 to 9.4 mg/L (highest in the North Bay Aqueduct due to local watershed sources), so it may be possible to achieve this source water quality target.

Actions have focused on developing organic carbon regulations (the Central Valley Drinking Water Policy project) and on controlling sources of organic carbon discharges in the watershed. The WQP has also funded studies of alternative treatment processes and mulitple disinfectants; these studies have reinforced the need to reduce organic carbon levels in water diverted from the Delta. Organic carbon also plays a critical role in the Delta food web, so studies have also been funded to determine the characteristics of organic carbon that support the food web and that result in disinfection byproducts. Early research suggests there may not be a conflict, but work is still needed to conclusively prove this.

The WQP has also funded limited nutrient projects; the CALFED Ecosystem Restoration Project's Dissolved Oxygen project (see fact sheet) has made progress on studying the nutrient and algae issues in the lower San Joaquin River. Nutrients and algae are the least well understood constituents; pathogens are the most difficult to accurately monitor.

Next Steps

The CALFED Water Quality Program is in the process of completing a Final Stage 1 Assessment Report to assess its progress, integrate the known science, identify Stage 2 actions and priorities, and develop performance measures for drinking water quality. This report will be finalized in September 2007, and focuses solely on drinking water. The future direction and next steps for drinking water quality will be greatly dependent on the direction set by the Delta Vision Process at the end of 2007.

Replacing the current through-Delta conveyance with a peripheral canal would significantly improve the source water quality for treatment plants that rely on the Delta, eliminate seawater entrainment and significantly reduce bromide. Organic carbon would also likely be reduced on average, as Sacramento River typically has low average concentrations, but there are some questions on peaking events and their effects on treatment plants. Other constituents of concern need to be better understood so that operations and treatment can adjust accordingly and provide affordable and reliable treatment far into the future.

The real issues of such a decision really come down to timing and cost – most major treatment plants have already adjusted to current Delta water quality and treated water regulations at some expense to their rate payers. If the drivers of such a decision are the anticipation of future degradation of water quality due to climate change, sea level rise, Delta island levee breaks, and/or population increases in the Central Valley, it will be important and prudent to develop the modeling capacity to understand the repercussions of such events prior to making large financial investments in infrastructure.

For more information

This fact sheet was developed by Lisa Holm, P.E., CALFED Water Quality Program Manager, based on the draft Final Stage 1 Assessment Report. The CALFED Water Quality Program is implemented by the US Environmental Protection Agency, the California Department of Public Health, the California State Water Resources Control Board, and the Central Valley Regional Water Quality Control Board, in cooperation with the US Geological Survey, the US Bureau of Reclamation, and the California Department of Water Resources. The draft Final Stage 1 Assessment Report was developed in cooperation with and through financial support from its implementing and coordinating agencies, and the Bay-Delta Public Advisory Water Quality Subcommittee.

Web Resources

CALFED Water Quality Program (website currently being revised and updated)
http://www.calwater.ca.gov/Programs/DrinkingWater/DrinkingWater.shtml

Central Valley Drinking Water Policy:
http://www.swrcb.ca.gov/rwqcb5/available_documents/dw-policy/index.html

California Department of Public Health – Division of Drinking Water and Environmental Health
http://www.dhs.ca.gov/ps/ddwem/dwp/default.htm

US Environmental Protection Agency
http://www.epa.gov/safewater/index.html

California Department of Water Resources – State Water Project
http://www.water.ca.gov/nav.cfm?topic=State_Water_Project

California Department of Water Resources Municipal Water Quality Investigations
http://www.wq.water.ca.gov/mwqi/mwqi_index.cfm

California Urban Water Agencies
http://www.cuwa.org

California State Water Resources Control Board Water Quality Programs
http://www.swrcb.ca.gov/quality.html